



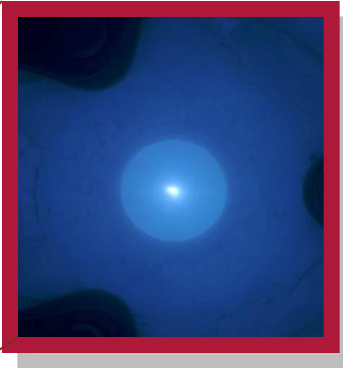
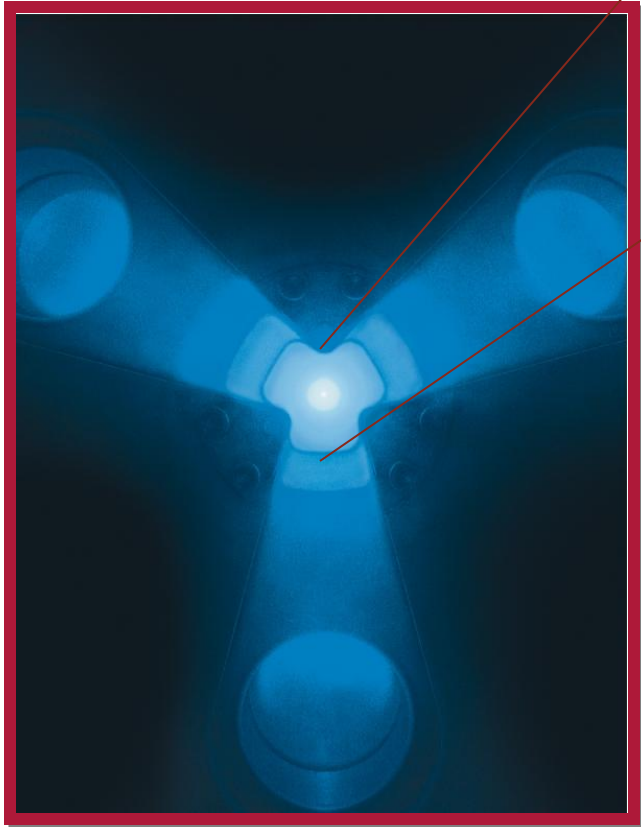
Electrodeless Z-Pinch™ EUV Source for Metrology Applications for Today and Future

Debbie Gustafson

Agenda

- Background on the EQ-10 Electrodeless Z-Pinch™ EUV source
- Characteristics of the EUV source
- Initial experiments for 6.7nm

EQ-10 Source



- Introduced in 2005
- $13.5\text{nm} \pm 1\%$ Power in 2π
 - 10W continuously
 - Now 20W
 - @2 kHz
- 10kHz operation also
- Operates continuously for days and weeks

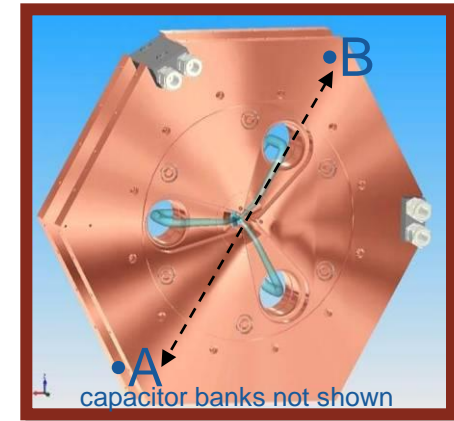
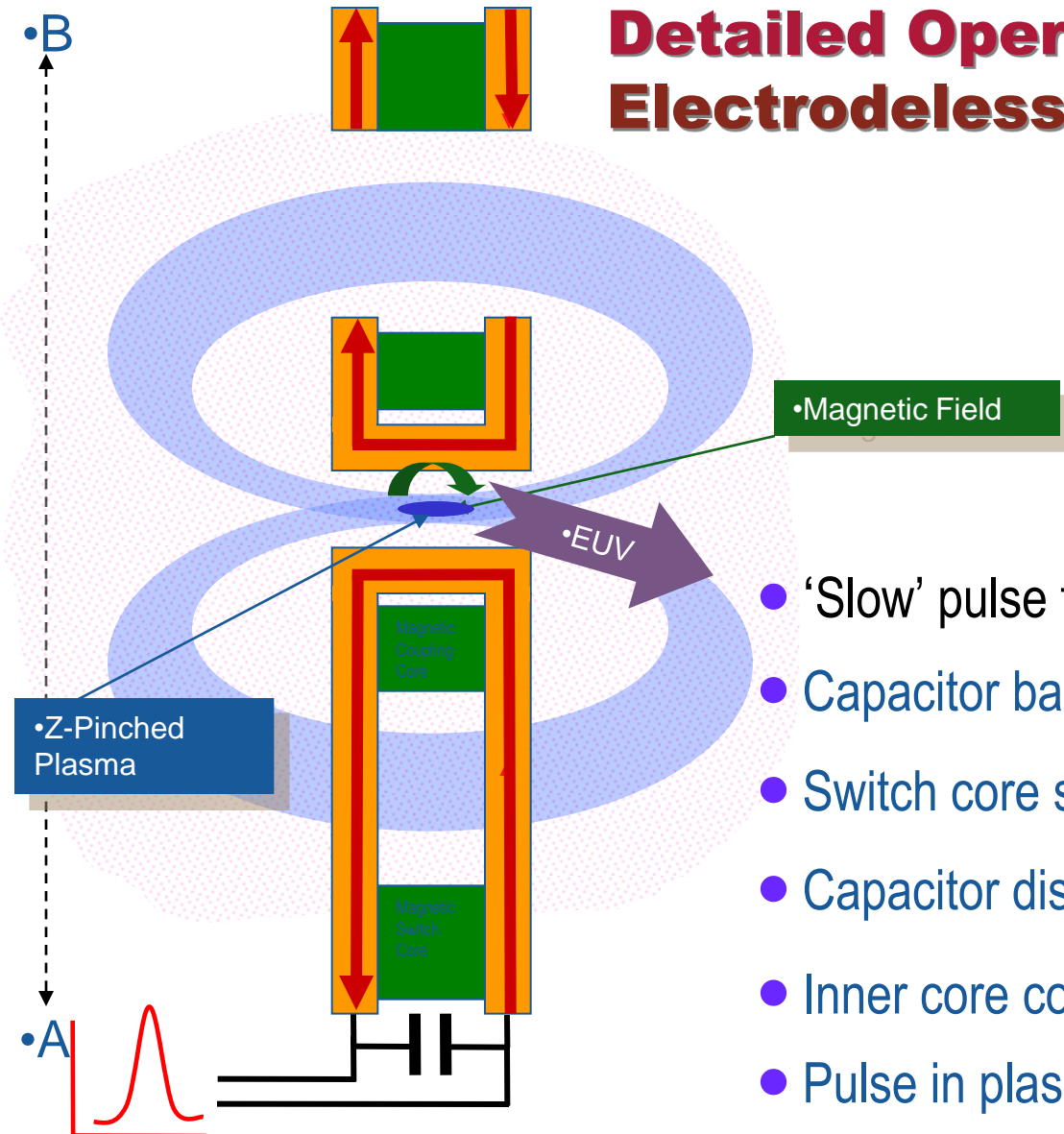
ENERGETIQ



ENERGETIQ™ EUV Source

Detailed Operation:

Electrodeless Z-Pinch™ EUV Source



- ‘Slow’ pulse from modulator
- Capacitor banks charge up
- Switch core saturates. Impedance $\Rightarrow 0$
- Capacitor discharges. (Pulse compression)
- Inner core couples current pulse to plasma loops.
- Pulse in plasma current \Rightarrow Z-pinch!

System Reliability

- Shipped over 22 sources in the field
 - 4 High Brightness Sources already shipped
- Installations in Japan, Europe and US
- Systems being operated 24/7 with minimal downtime
- Systems integrated into tools for research and development
 - Actinic Inspection
 - Resist Outgassing
 - Mask Contamination
 - Optics Testing

Sample of Current Installations



EUV Technology Outgassing Tool Installed at IMEC



Flood Exposure system installed at Osaka University (Tagawa Lab)

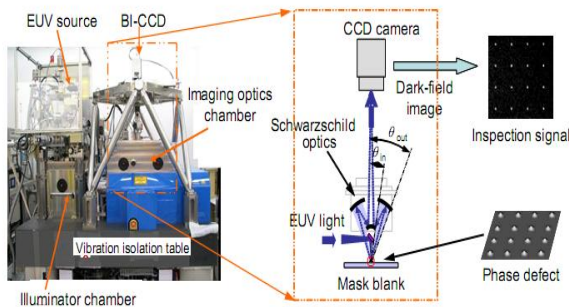


Figure 2 Actinic mask blank inspection tool built at MIRAI-Selete clean room and concept of its inspection optics using dark-field imaging.

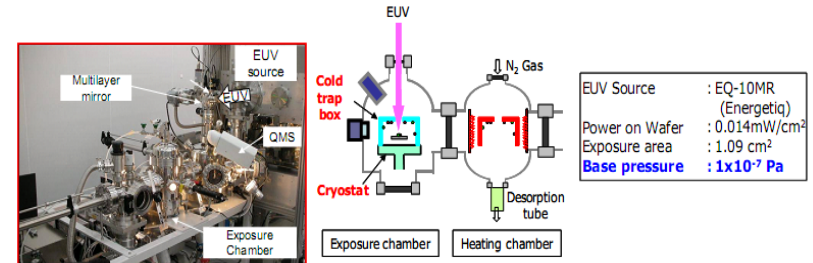


Figure 2. Photograph and schematic of resist outgassing evaluation tool used for GC-MS method.

Actinic Mask Inspection Tool at EIDEC

LithoTech Outgassing Tool installed at EIDEC



Recent Improvements in EQ-10 Brightness and Power

EQ-10 Product Family



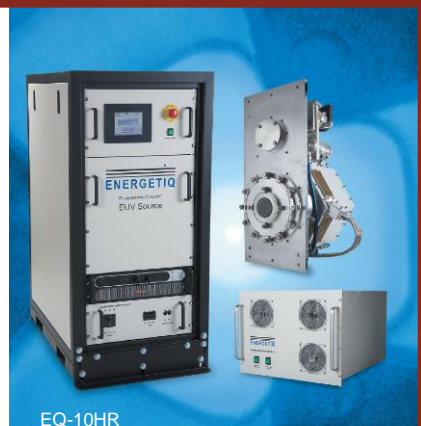
EQ-10
High-Reliability,
High-Stability
10Watt EUV
Source for EUV
R&D

EQ-10HP
High-Brightness
20Watt EUV
Source for
Metrology and
Testing



EQ-10SXR
Soft X-Ray Source
for Water-Window
Microscopy and
6.7nm R&D

EQ-10HR
High Repetition-
Rate EUV Source
for Accelerated
Optics Testing



Actinic Mask Inspection/ Metrology

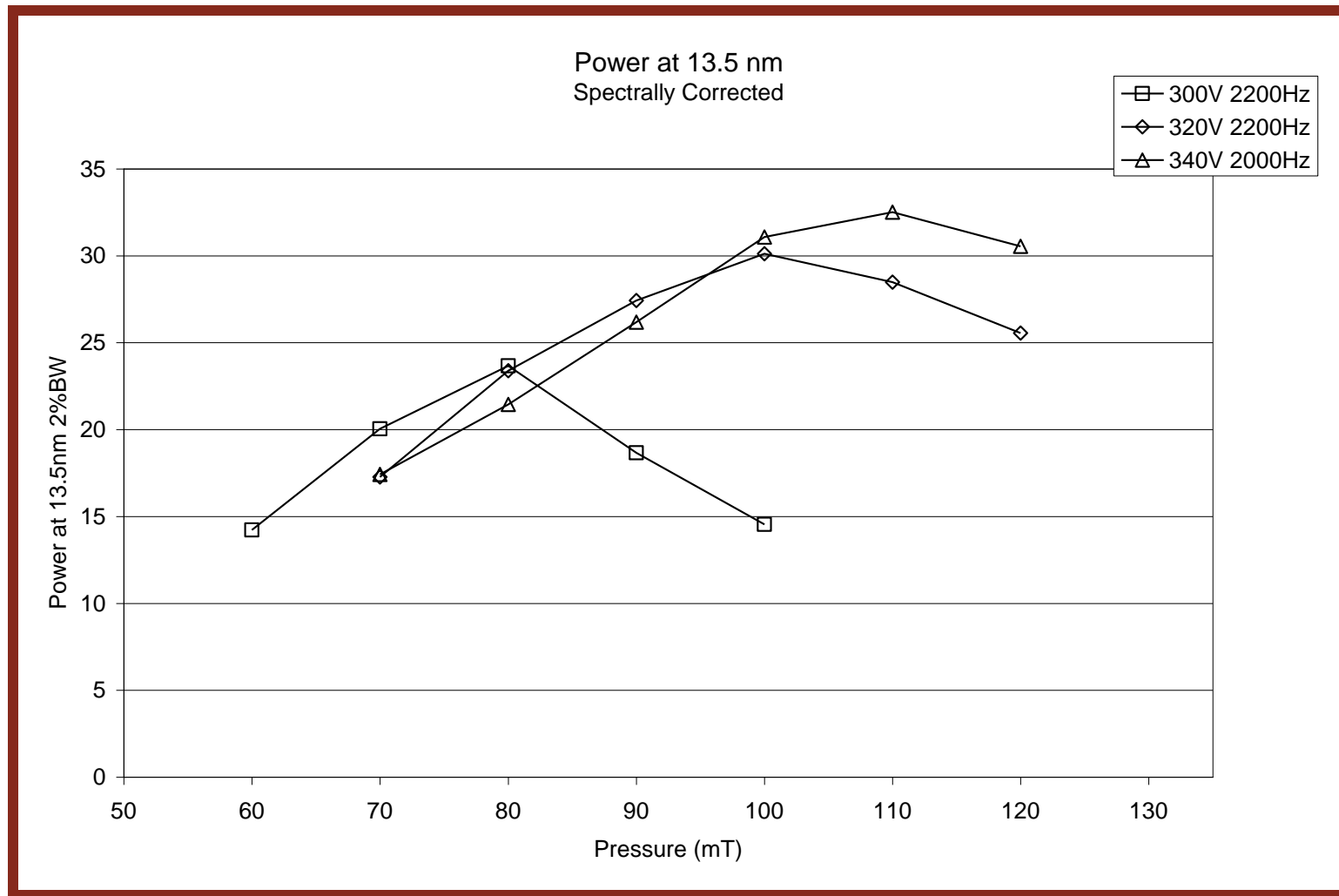
- Actinic Blank Inspection, AIMS and Patterned Mask Inspection are critical to the success of EUV lithography
- Major OEMs are being funded and have programs for development of these tools
 - Funding by both Sematech EMI and EIDEC (Japan)
- There is no commercial source on the market to meet the “production” needs for these tools
- Minimum brightness specifications are $10 \text{ W/mm}^2\text{-sr}$ for Prototype tools

EQ-10HP Overview

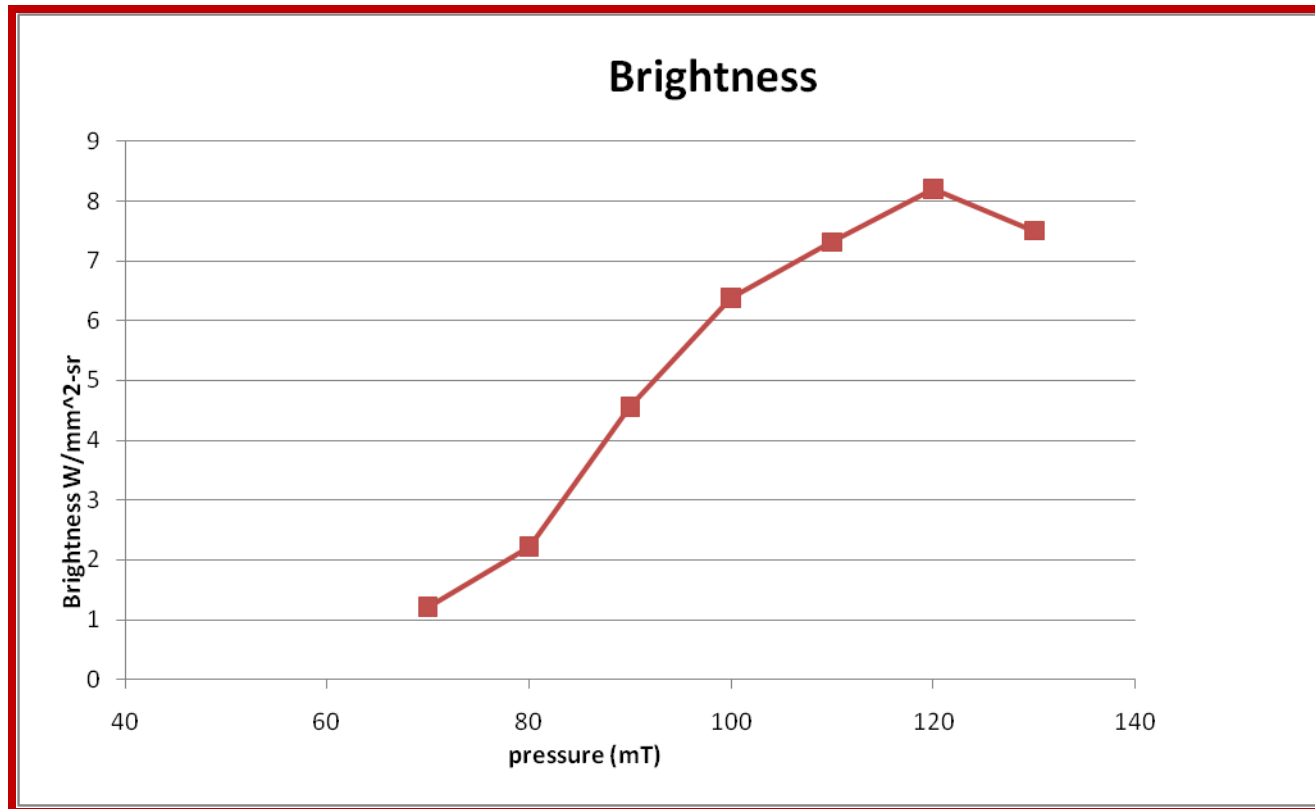
- Based on standard EQ-10 High Reliability Source
 - Utilizes new better cooling bore design
 - Improved modulator
- Design allows for up to 7kW input power
 - Improved cooling of source and modulator
- Specifications
 - >20 W of $13.5\text{nm} \pm 1\%$ Power in 2π
 - ~ 8 W/mm²-sr brightness



EQ-10HP EUV Power vs. Pressure



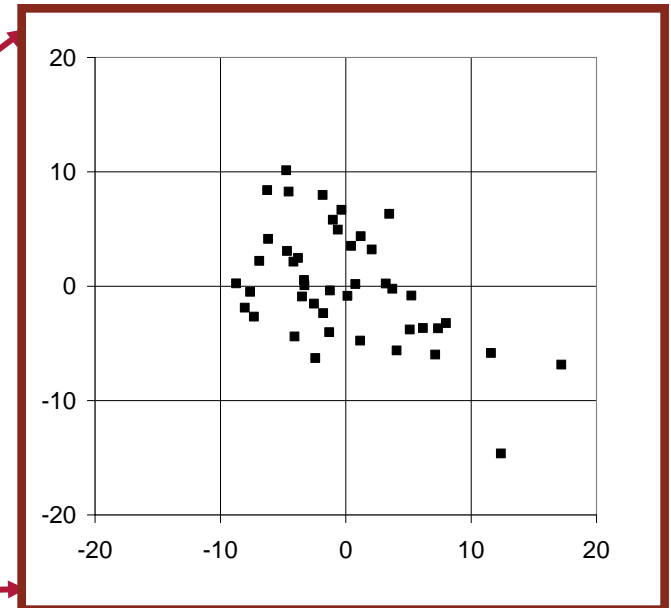
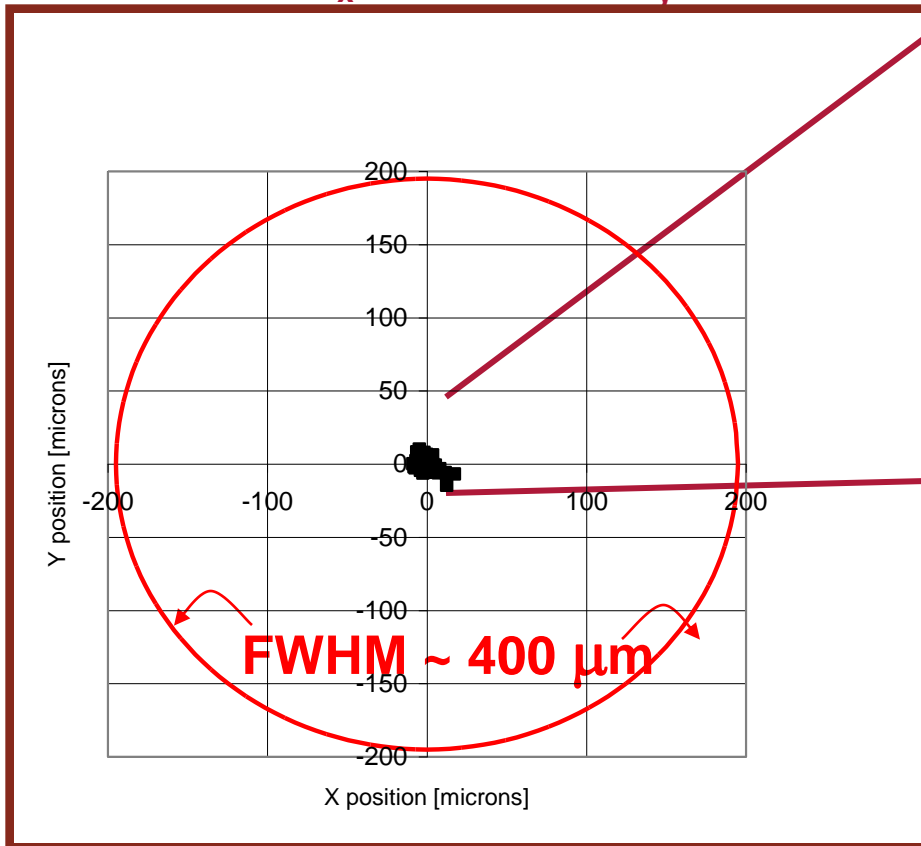
Optimizing Brightness with Power and Pressure



Stability in EUV Plasma Position **ENERGETIQ**

- Image recorded once an hour for over 300 million pulses (~44hours) of continuous operation. Position then extracted from images:

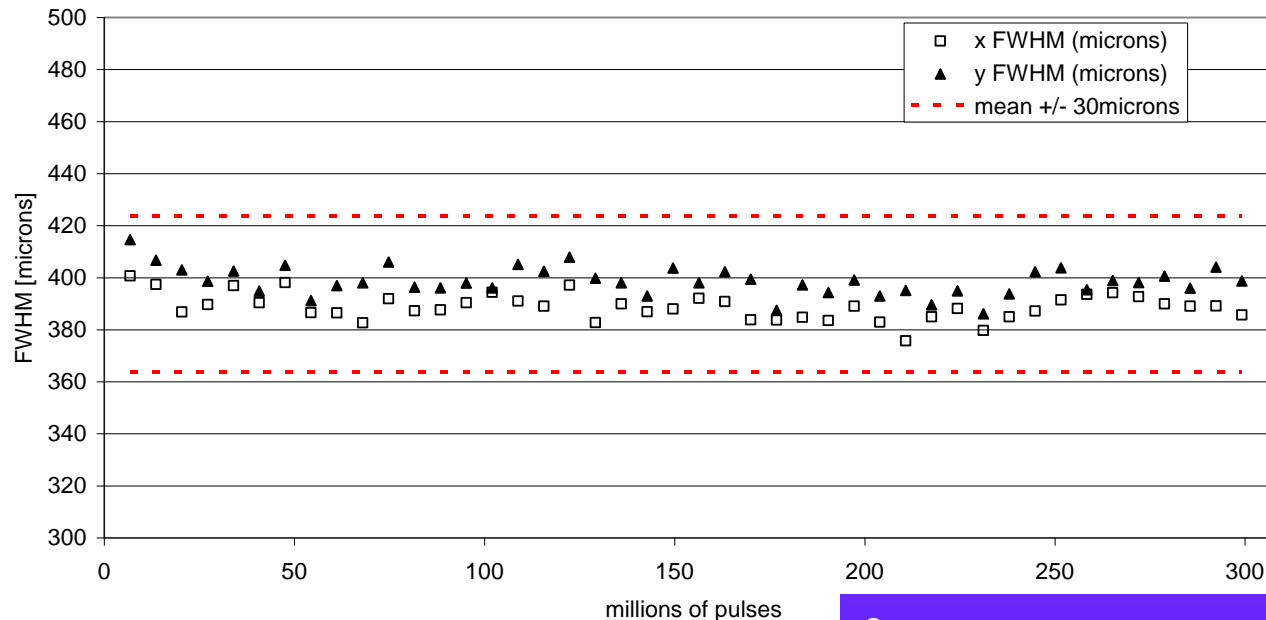
– Position: $\sigma_x = 5.8 \mu\text{m}$ and $\sigma_y = 5.0 \mu\text{m}$



- Brightness remains constant
- This is open-loop stability:
No feedback!

Stability in EUV Plasma Size

- Image recorded once an hour for over 300 million pulses (~44hours) of continuous operation. Size then extracted from images:
 - Size: $\sigma_{FWHMx} = 3.1 \mu m$ and $\sigma_{FWHMy} = 3.6 \mu m$



- Brightness Remains Constant
- This is open-loop stability: No feedback!



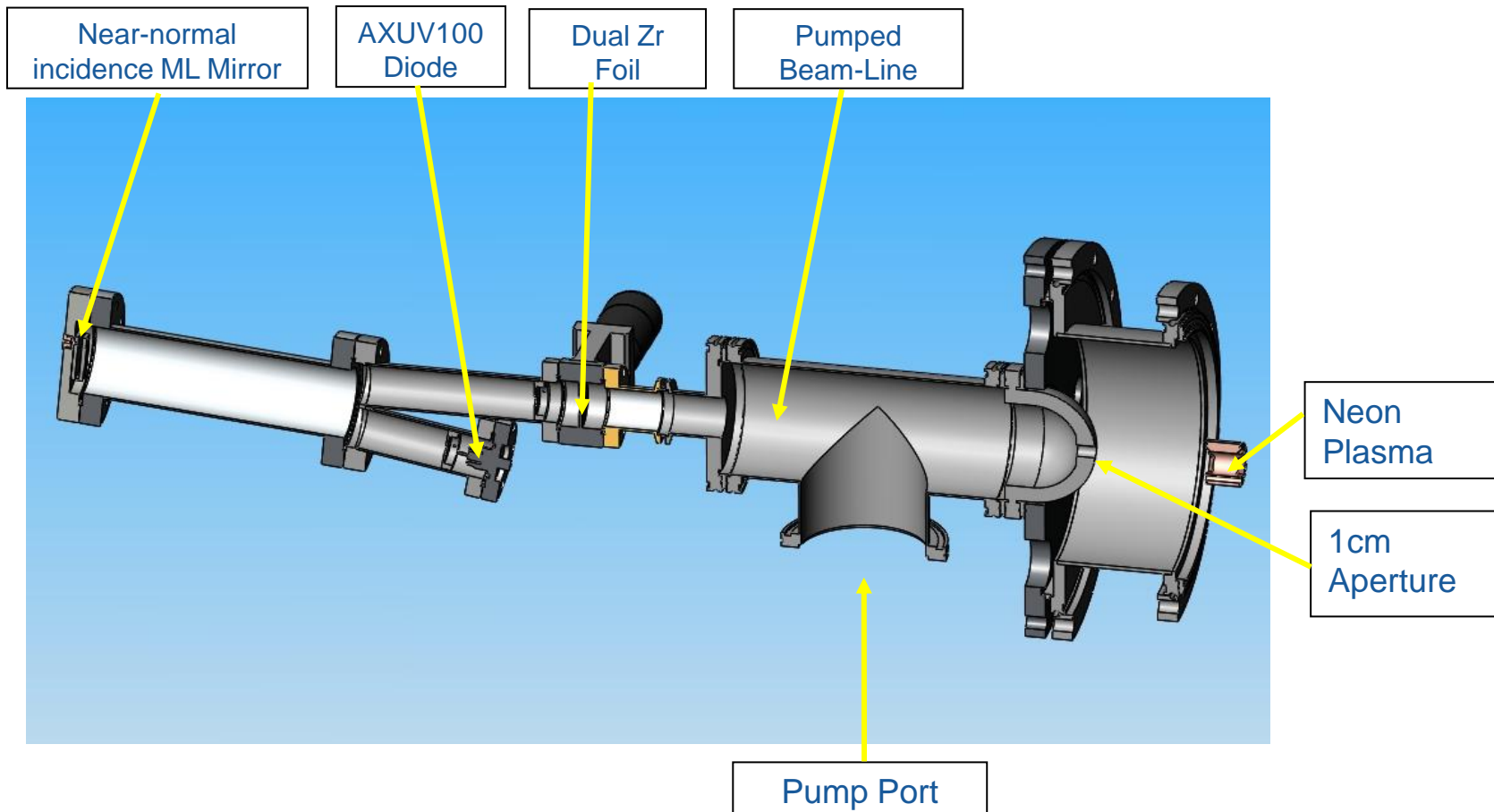
**EQ-10 for 6.7 nm for
Resist Development**

Selection of gas:

- NIST spectral database used;
http://physics.nist.gov/PhysRefData/ASD/lines_form.html
- Search for lines with high relative intensity: The only gas which appears is Neon

Ion	Observed Wavelength Vac (nm)	Rel. Int. (?)	A_{ki} (s^{-1})	Ac c.	E_i (eV)		E_k (eV)	Configurations			
Ne VIII	6.5822	1000	3.50e+10	B	15.88881	-	[204.2389]	$1s^2 2p$	-	$1s^2 5d$	
Ne VIII	6.5895	1300*	4.19e+10	B	16.09330	-	[204.2429]	$1s^2 2p$	-	$1s^2 5d$	
Ne VIII	6.5895	1300*	6.97e+09	B	16.09330	-	[204.2389]	$1s^2 2p$	-	$1s^2 5d$	
Ne VIII	6.7382	1500*	3.97e+10	B	0.0000	-	[184.0070]	$1s^2 2s$	-	$1s^2 4p$	
Ne VIII	6.7382	1500*	3.97e+10	B	0.0000	-	[183.9816]	$1s^2 2s$	-	$1s^2 4p$	

Diagnostic:

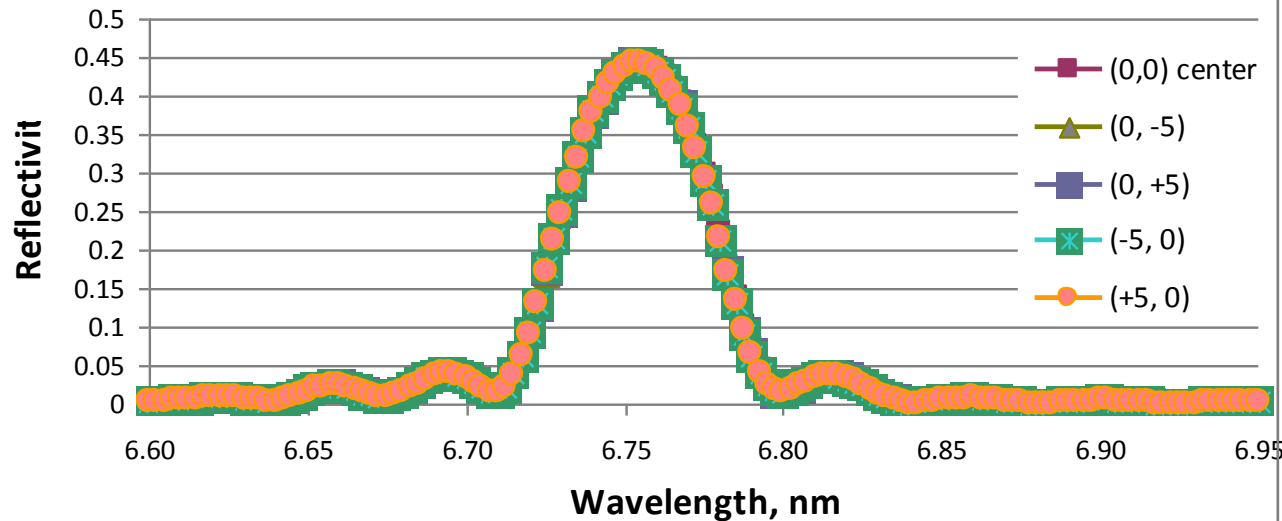


Diagnostic: Mirror

- In-band measurement via custom mirror. Fwhm 0.75% (very narrow)

R(peak), %	CWHM, nm	Lpeak, nm	FWHM, nm
44.31	6.754	6.755	0.051

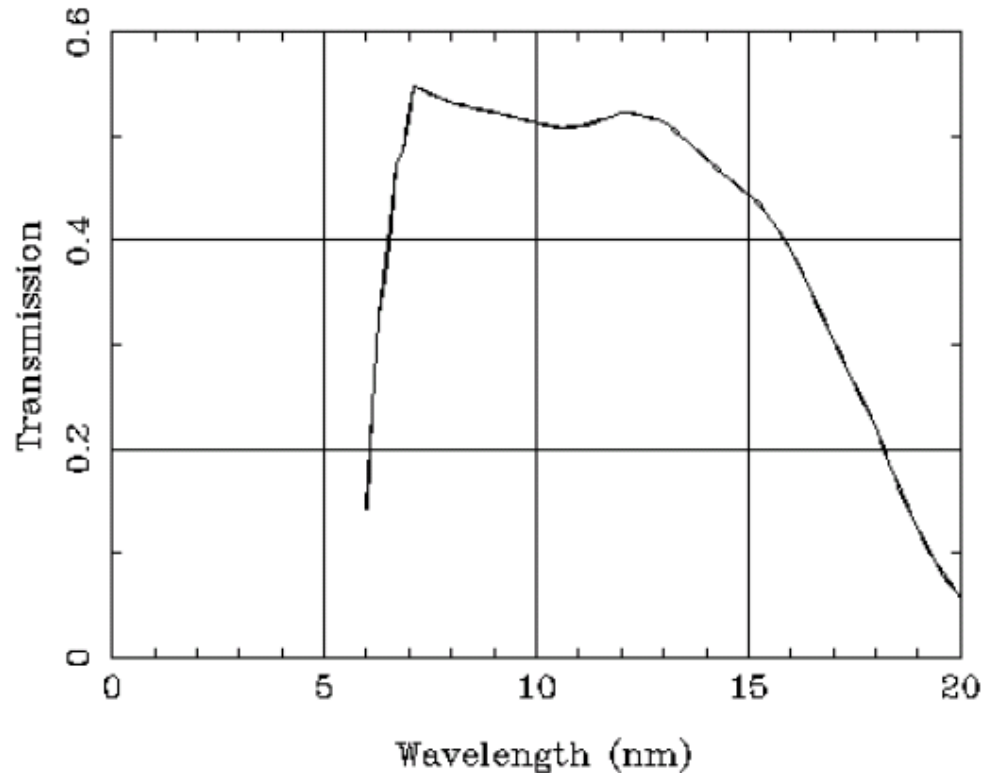
Measured at CXRO reflectivity of XRO#34158-7
at 5 degrees off normal



•Mirror made by Rigaku

Foils: use Zr...

Zr Density=6.506 Thickness=0.2 microns

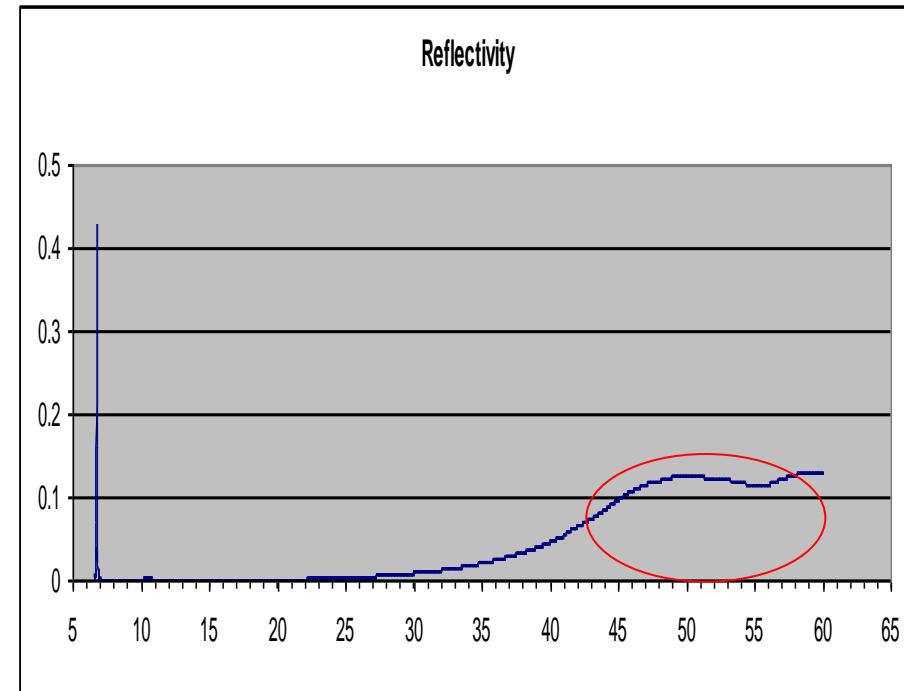
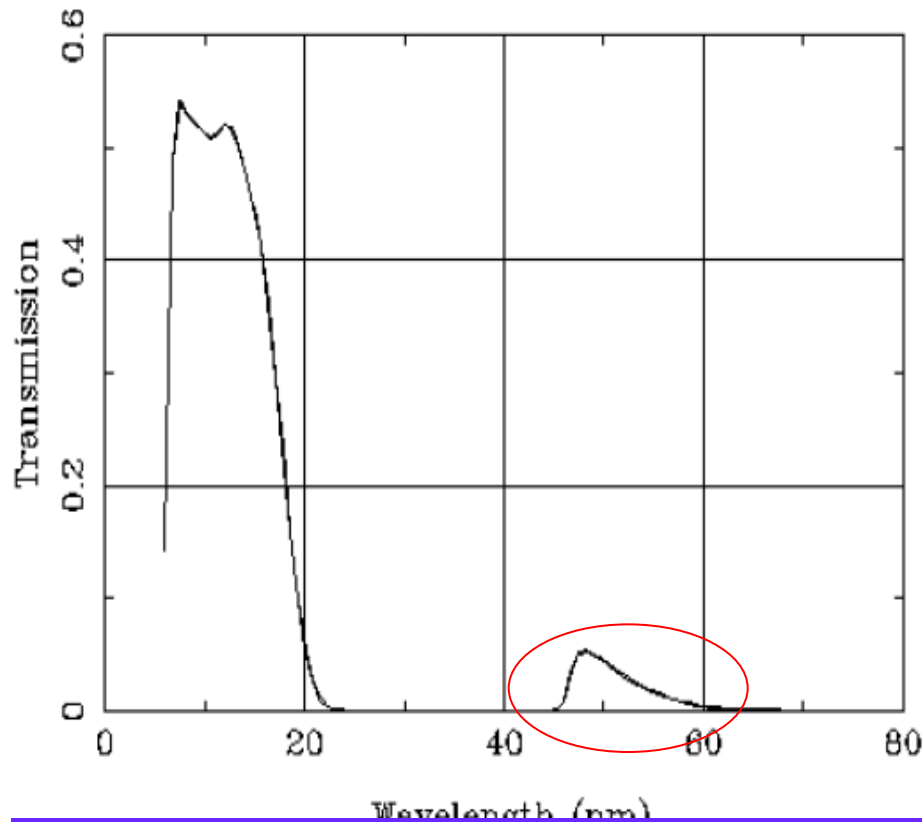


- Transmission at 6.7382 nm ~ 0.48 –
- On grid (82% transmission)
- Net transmission ~ 0.39

Zr has a problem at low energy...

- Need to check mirror reflectivity at low energy...~ 10% . Neon has many strong lines here. So need additional filtering....

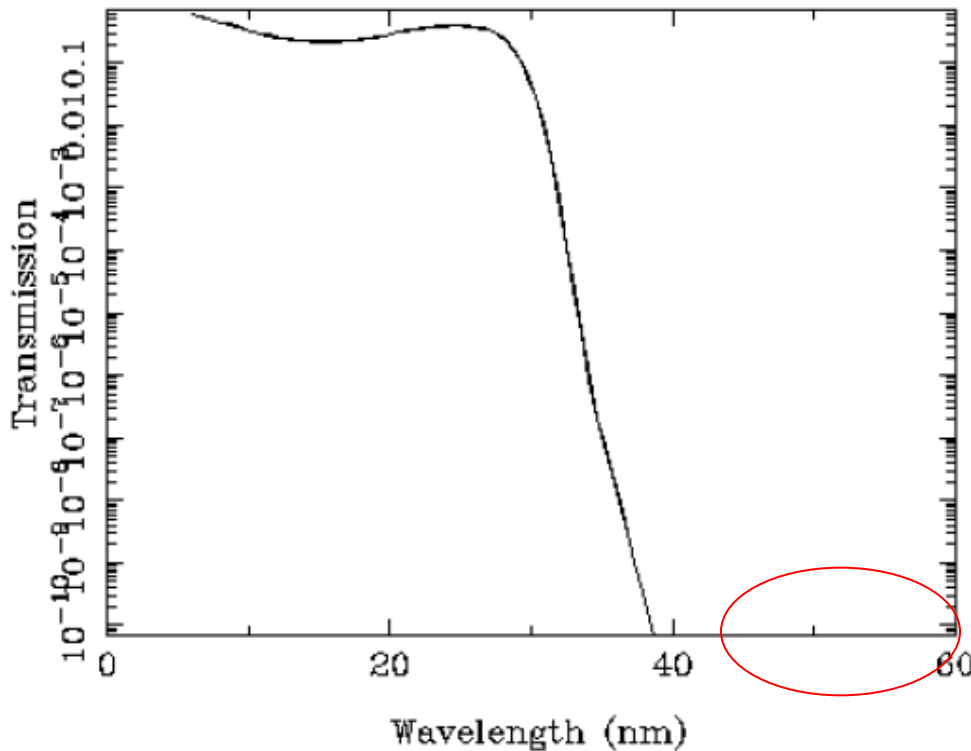
Zr Density=6.506 Thickness=0.2 microns



Gas filtering...

- Argon works well. $\sim 10^{-10}$ transmission 40-60 nm
- Transmission at 6.7nm $\sim 54\%$. (Neon also was used...)

Ar Pressure=0.4 Path=80. cm



Results:

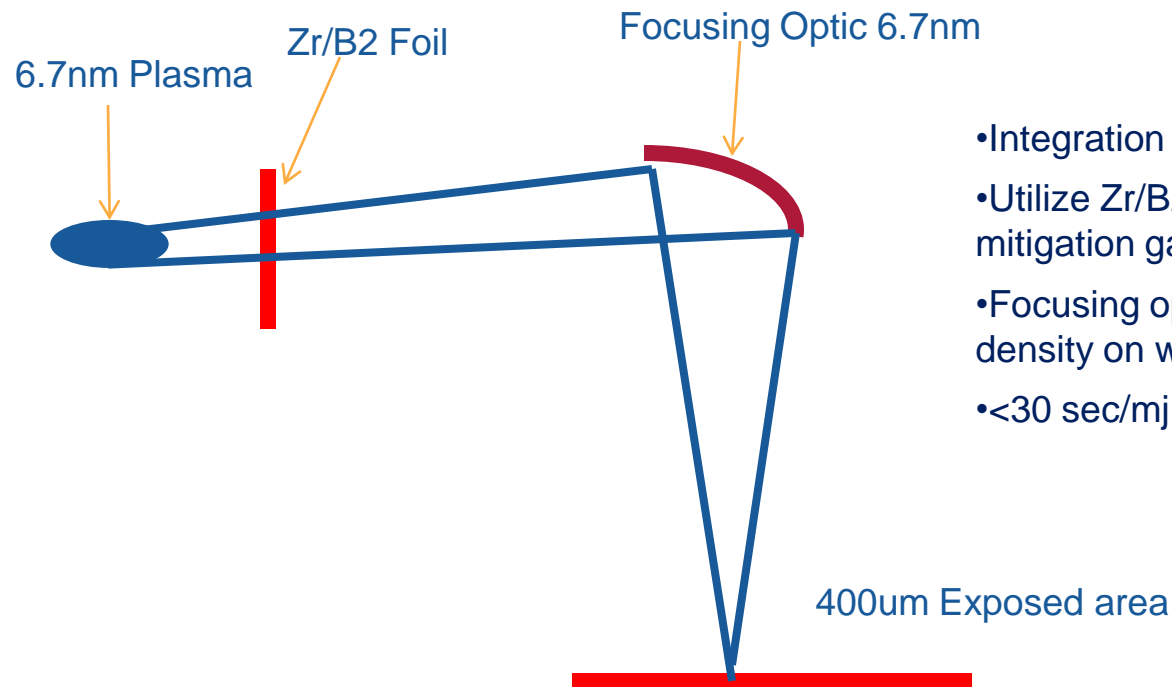
Measurement with Ar filter gives reasonable foil transmissions. (theoretical ~ 0.4)

- Best 2pi pwr-- ~ 70 mW

	torr	cm	Ar trans.				
	0.222	81.9	0.71	frac.		Diode	Pwr, mw
foil	signal (na)	foil trans.		2 pi	mirror	A/W	2 pi
t1	3.380E+00	0.296	0.71	2.45E-06	0.37	0.25	71.0
t2	3.480E+00	0.305	0.71	2.45E-06	0.37	0.25	71.0
t12	1.030E+00	0.090	0.71	2.45E-06	0.37	0.25	71.0

•430 V, 1100 Hz, 5.5 kW DC power, 400 mT process pressure

How can this be utilized?



- Integration into sensitivity Measurement tool
- Utilize Zr/B2 foil eliminates need for Ar mitigation gas
- Focusing optic at 6.7nm increases power density on wafer by more than 100x
- <30 sec/mj exposure time at wafer

Closing Remarks

- The Energetiq EQ-10 EUV source is a reliable and stable source of EUV photons.
- The system is being operated in the field 24/7 with consistent operation over years!
- Energetiq Sources are being used for infrastructure development globally.
- Redesign of the source offers higher power and higher brightness operation
 - Brightness of $\sim 8\text{W/mm}^2\text{-sr}$
 - $20\text{W}/2\pi$
 - Continued excellent plasma and pulse-to-pulse stability
- The high power version of source is capable to running Ne for 6.7nm development

Acknowledgements

- The team at Energetiq...
- Our valued customers...
- Our excellent partners and collaborators...



Thank You

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